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Measuring the Contribution of New Varieties to Increasing Wheat Yields

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An evaluation of the contribution of wheat breeding to increasing yields on farms can be accomplished by an examination of the effect on farm production of changes in varieties and other inputs using a production function. Three different means of representing the effect of varietal change in a production function are identified, and the advantages and limitations of these are discussed. An empirical analysis of each is presented for the Mitchell Shire in southern N.S.W. The evidence suggests that the different measures are not highly correlated, so the choice between them can be critical to the results obtained from a full examination in a production function.

1. Introduction

As resources for research are limited, it is important to those allocating funds to know the likely returns from different forms of research. One means of evaluation is to examine the contribution that has been made in the past by various forms of research.

In this context, there is interest in evaluating the contribution of wheat breeders to the wheat industry in Australia. Since the time of Farrer, new wheat varieties have been released to farmers regularly from wheat breeding programmes. However, the success of breeders in making progress with wheat yields has been questioned by Campbell (1977).

Wheat breeders have had goals which are far wider than direct yield increases. Evans (1980) cited a list of desirable plant breeding attributes presented by William Farrer in 1891, in which only the eleventh (and last) mentioned yield. While it is likely that breeders have made substantial contributions to the improvement of quality and disease resistance in wheat, the extent to which yield increase can be attributed to breeding programmes is an important question.

Warren (1969) pointed out that "one would expect a steady increase in yield to have resulted from the use of the better varieties" (p. 247).

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Nevertheless, Warren could find no evidence of a steady upward trend in wheat yields in southern N.S.W. between the early 1920s and 1950s. Warren suggested two factors which might help explain the apparent failure of wheat breeders' efforts to lead to steady increases in wheat yields on farms:

(a) significant differences in experiments may not be significant on farms; and

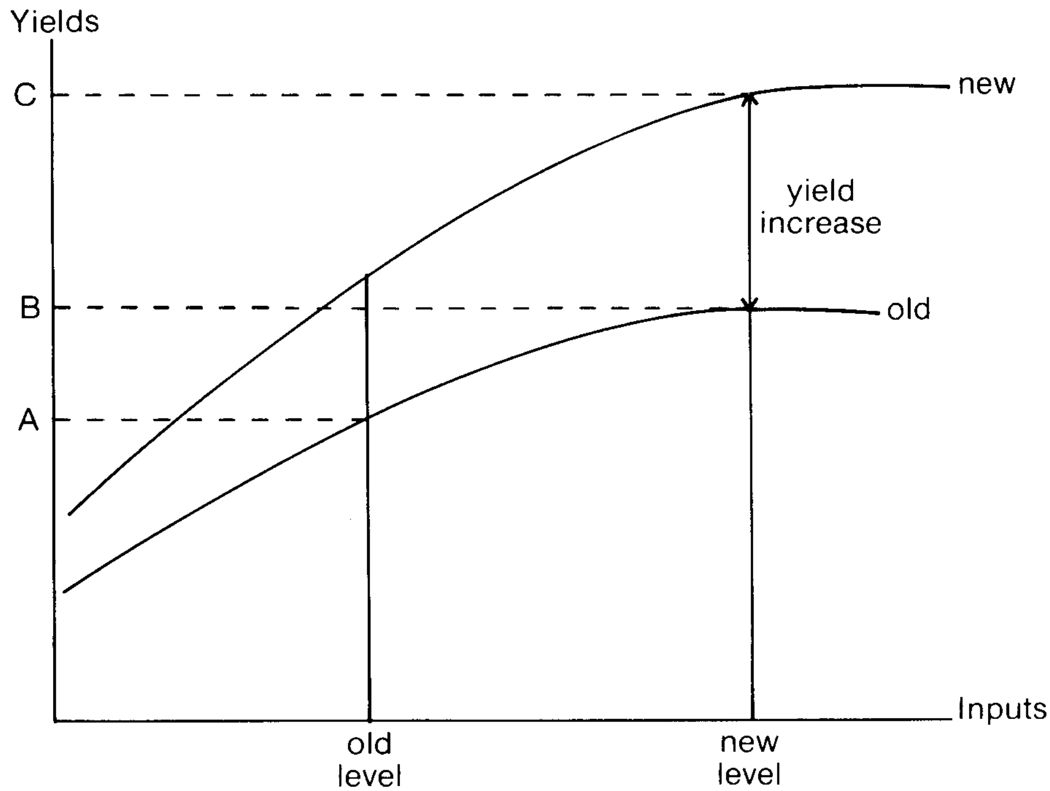
(b) where breeders aim to replace varieties whose yield is declining because of increased susceptibility to disease or increasing unsuitability to changing agricultural practice, there may not necessarily be any increase in yield when the varieties are compared at their times of peak yields. Thus the constant need for "maintenance" breeding may have prevented breeders from increasing yield potential.

In another study of yield trends, Russell (1973) found that there was an upward trend in Australia's wheat yields between 1936 and 1968, but that the rate of increase was only about half of that of the United States. Russell found that wheat yields had increased only marginally faster than barley yields, and attributed this difference to the greater breeding effort.

Davidson and Birch (1980) and O'Brien (1982) planted varieties of historical importance in trials and compared the yield increases which occurred as the year of release increased. Davidson and Birch found that there were long periods when no apparent signs of increase in yield potential occurred, and that increases in yield potential seem to have occurred in steps at lengthy intervals. O'Brien also found that the path through time of varietal yields was not smooth, and that there were periods when new varieties did not exceed the yields of older varieties. Nevertheless, he found substantial improvement over time in the yields of varieties.

O'Brien used the changes in variety yields over time to attempt to measure the extent to which the new varieties had contributed to increases in farm yields. He found that varieties grown around 1900 yielded about two-thirds of the recently-released varieties, and concluded that current production would be only 67 per cent of its present level if there had been no variety improvement. There are flaws in this approach which make these conclusions questionable (Brennan 1983). The first major flaw is that O'Brien's approach fails to take account of the effects of other inputs. Each variety will have different relative responses to changes in these inputs (Godden and Powell 1981). Plant breeders often increase yields by exploiting yield and management interactions (Byerlee and Harrington 1982). For example, if the new varieties give greater response to fertilisers, the evaluation of the contribution of the variety requires analysis of adoption of different fertiliser levels. Yield increases are then measured as the difference between the new and old response functions at the new level of fertiliser (see Figure 1). Austin *et al.* (1980) also noted that the increase yield of new varieties may depend on high soil fertility if they have been selected on soils of progressively increasing fertility. Thus the contribution of new varieties to increases in average yields would be overstated (that is, AC rather than BC in Figure 1).

Figure 1: Interaction of Management and Variety on Yields



Source: Adapted from Byerlee and Harrington (1982).

A second major failing is that changes in experimental yields may overstate the changes that would occur on farms. Davidson and Martin (1965) found that a definite curvilinear relationship appeared to exist between yields obtained on farms and in experiments. Thus the percentage advantage in yields that a new variety shows in trials is likely to be lower on farms on average. If this is the case, a measure based on trial results is likely to overstate the yield improvement on farms from the use of the new varieties.

Third, O'Brien's approach did not make an allowance for differences in the adoption rates for different varieties. Without such an allowance for the varieties that farmers are actually growing, comparisons of experimental yields will fail to relate to farm yields.

Therefore, an evaluation of the contribution of wheat breeders to increasing yields on farms requires more than an examination of the relative movement of national or State average yields and an analysis of relative yields from trials. It requires an examination of the effect on farm production of changes in varieties grown by farmers; it needs to allow specifically for changes in the amounts of other inputs used and any interactions between varieties and these inputs; and it should allow for differences between the rates of increase in farm and experimental yields. One approach which enables these requirements to be met is to incorporate a measure for varietal change in an aggregate production function.

A production function indicates that the production (P) of a crop is determined by the mix of inputs (X_i) used. Thus

$$P = f(X_1, X_2, ..., X_n). \tag{1.1}$$

As pointed out by Heady and Auer (1966), there are numerous specific inputs which determine production, such as land of a particular quality, rainfall in a particular week, the yield potential of a particular variety and the use of a particular herbicide. Since data restrictions prevent estimation in this much detail, specific variables must be aggregated into manageable input variables. Three measures have been identified as possible means of representing the effect of varietal change in a production function, namely the "index of varietal newness", the proportion of the area planted to recently released varieties, and the "index of varietal improvement".

The aim of this paper is to describe and evaluate these measures and to report an empirical examination of them using data from the Mitchell Shire in southern N.S.W. This will enable some conclusions to be drawn as to the most appropriate means of incorporating the effect of varietal improvement on yields in a production function.

2. Index of Varietal Newness

2.1 Use of the Index

The index of varietal newness has been used by Johnson and Gustafson (1963) to examine the contribution of new varieties to U.S. grain yields. The index measures the relative "newness" of the varieties grown by estimating the proportion of the area sown to varieties not sown in earlier periods. They found that an increase of about 0.1 tonnes per hectare in average wheat yields in the western States of the U.S. from the 1930s to about 1950 appeared to be attributable to the adoption of new varieties. This represented about 60 per cent of the total increase in yields. In the eastern States, no significant effect of new varieties was found.

Johnson and Gustafson (1963, pp. 69-70) used this index in preference to more complex measures of "varietal improvement" because of its simplicity and the fact that it was "more readily usable in possible future studies or projections".

2.2 Construction of the Index

The index of varietal newness used by Johnson and Gustafson was constructed as follows:

$$\text{Define } z_{it} = p_{i,t} - p_{i,t\text{-}5} - 2p_{i,t\text{-}10} - 3p_{i,t\text{-}15} - \ . \ . \ . \tag{2.1}$$

where $p_{i,t}$ is the percentage of total area sown to variety i in year t, and where the subscripts t-5, t-10, t-15, ... refer to 5, 10, 15, ... years earlier.

Let $x_{it} = z_{it}$ if $z_{it} \geqslant 0$, and (2.2a)

$x_{it} = 0$ if $z_{it} < 0$. (2.2b)

Then $I_t = \Sigma_i x_{it}$ (2.3)

where I_t is the value of the index in year t.

For each year, the relative importance of varieties which were more popular than they had been in earlier periods was established. The index measures the rate of change of varieties rather than the level of yields of these varieties.

The particular form of the index (2.1) used by Johnson and Gustafson was determined by the availability of data, as the only comprehensive data on the popularity of wheat varieties in the U.S. were collected every five years. Thus there could be some modifications to the precise form of the index where there were annual data on the popularity of varieties.

In a more general version of the index (consistent with that of Johnson and Gustafson), z_{it} may be defined as follows:

$$z_{it} = p_{i,t} - p_{i,t-n} - 2p_{i,t-2n} - 3p_{i,t-3n} - \dots \qquad (2.4)$$

where n is a smaller integer than five. For values of n other than five, a different definition of "newness" to Johnson and Gustafson's is implied.

The precise form of the index used (that is, the choice of the value of n) would be determined by the aims of the researcher and the data available.

2.3 Relative Merits of the Index of Varietal Newness

A major limitation is that the index does not give any indication of effects on yields, and therefore production, but merely measures the adoption rate of varieties. Where motives for adoption other than higher yields are important, such as improved disease resistance or higher quality or legislative control, this index will still indicate a contribution from breeders. However, since it measures the rate of change of varieties rather than their contribution to yields, the index is difficult to interpret in a production function. In this respect, the findings of Johnson and Gustafson need to be interpreted with caution.

A second limitation of the index of varietal newness is that it relies on full information for its accuracy and practical effectiveness. Thus if a variety is in an "other/unspecified" category in one period but is individually specified in a later period, errors can occur in the calculations. These problems can be compounded where the only data are for leading varieties, as in Macindoe and Walkden Brown (1968). Where the coverage of varieties is incomplete, ideally some adjustment should be made. However, if the proportion of "other/unspecified" varieties changes widely over time, there is no way of knowing whether this group has a larger or smaller proportion of new varieties. If this group is made up mainly of older varieties, this lack of complete coverage may not be important, but if it includes a major proportion of new varieties the lack of complete coverage could markedly affect the index in some years. The calculations imply that varieties for which there are no data were not grown at all.

A third limitation is that while there is no need for detailed data on relative yields, the time period for which the index can be calculated is limited by lack of data on varietal popularity. This is particularly the case for areas where popularity data are not available over a long period, such as for shires or regions. For Australia as a whole, or for the States, it is likely that such an index might be more useful. At this level relatively long series of variety popularity data are available from sources such as Macindoe and Walkden Brown (1968). For disaggregated areas such as shires, data may only be available for twenty years. In this case, it may be possible to construct an index of varietal newness for only five to ten years.

3. Proportion of Recent Varieties

A simpler indicator of varietal change is the proportion of the total area that is planted to recently released varieties. Thus let

$$q_{it} = p_{i,t} \text{ if year of release} \geqslant t\text{-}m, \qquad (3.1a)$$

$$q_{it} = 0 \text{ if year of release} < t\text{-}m \qquad (3.1b)$$

where m is the number of years used to define "recent".

$$\text{Then } I_t = \sum_i q_{it} \qquad (3.2)$$

where I_t is the proportion of the total area that is sown to varieties released in the previous m years. This measure is simple to calculate, although it is open to debate on the definition of "recent". There is a lag of about two years between the release of a variety and widespread availability of seed for farmers, so only small areas are likely to be planted in the first two years. The minimum meaningful period is likely to be three years.

This measure has many limitations in common with the index of varietal newness. It is an indication of the rate of adoption of new varieties, without indicating whether the reason for the change was related to improved yields. Thus it can be difficult to interpret in a production function, since varieties can be adopted for 'non-production' reasons. Similarly, lack of full information on new varieties can create inconsistencies in the measure. However, it has the advantage over the index of varietal newness that it can be calculated for the full period of the variety data if release dates are known.

The date of release may not, however, be a good determinant of availability. If poor seasons followed the release of a variety, seed increase could slow the rate of adoption. Also, there can be problems where a variety was originally released in another region, or for a specific purpose such as irrigation, and only at a later stage was recommended for use in the parti[illegible] region under study. The use of the original release date would introduc[illegible]r into the analysis.

Despite these limitations, this measure has the major advantage that it is very simple to calculate. The definition of "recent" again would be determined by the aims of the research and the data available.

4. Index of Varietal Improvement

4.1 Use of the Index

An index of varietal improvement, or index of area-weighted relative yields, is calculated by weighting the relative yield of each variety by its popularity with growers (that is, the proportion of the area sown to that variety). This approach has been used by Auer (1963), Heady and Auer (1966) and Silvey (1978, 1981). Auer examined the contribution of variety improvement in nine crops in the U.S. in the 1940s and 1950s. For wheat, Auer found that variety improvement had led to increase in yields of 0.14 tonnes per hectare between 1939 and 1960, representing 28 per cent of the total increase over that period. Silvey examined the contribution of new wheat, oats and barley varieties in England and Wales from 1947 to 1978 using this index. For wheat, Silvey found an increase of 1.52 tonnes per hectare attributable to varieties, representing about 63 per cent of the total increase in average wheat yields over that period. However, Silvey failed to take account of changes in other inputs, and appears to have overstated the contribution of new varieties along the lines indicated in Figure 1. Silvey also implied that farm yields increase at the same rate as experimental yields, which may have led to further overstatement.

4.2 Construction of the Index

An index of varietal improvement can be specified as:

$$I_t = \sum_i (p_{it} \; v_{it}) \tag{4.1}$$

where I_t is the index value in year t, p_{it} is the proportion of the i^{th} variety in the crop in year t, and v_{it} is the yield of the i^{th} variety relative to a base variety in year t.

This form of the index requires that there be a complete set of data for yield and popularity for each variety grown on farms in each year. Where complete data are not available, an adjustment is needed to correct for the proportion of varieties not included. The adjustment can be incorporated as follows:

$$I_t = \sum_i (p_{it} \; v_{it}) \; / \; \sum_i p_{it}. \tag{4.2}$$

This adjustment is exact if the varieties not included perform equally as well as the average of all varieties included. The closer that $\sum_i p_{it}$ is to unity in each period, the less important is the adjustment process.

Ideally, relative yields from farms would be used in the index. However, in Australia there are no reliable data on relative yields at the farm level. While some data on receivals by variety are available, for several reasons they do not produce reliable estimates of relative yields when combined with data on area sown to each variety:

(a) Some five to ten per cent of production normally is retained on farms for feed and seed. Only if the same proportion of each variety is retained would relative yields be unaffected. Since it is more likely that seed of superior varieties would be retained, their yield advantages would be understated. There may be an opposing bias towards retaining inferior varieties for feed.

(b) There may be mis-statement of varieties on delivery, especially since dockages and premiums are determined on a varietal basis.

(c) Wheat produced in one region can be delivered in another region or State.

The only reliable sources of relative yields are variety trials. However, comparative variety trials are often performed using different varieties from those currently popular with farmers in the region. Older varieties either well known or considered no longer of interest may be excluded from trials in favour of promising newer varieties, even though they may still be commonly grown by farmers at that time. To limit the analysis to those varieties which were included in trials might severely restrict the coverage of varieties in some years (that is, $\sum_i p_{it}$ would be markedly below unity), and would mean discarding essential information. An alternative approach is to use relative average yields, based on the results of all the trials in which a variety was included, rather than the relative yields of each particular year. Thus the modified form of the index would be as follows:

$$I_t = \sum_i (p_{it} \; v_i) \; / \; \sum_i p_{it} \qquad (4.3)$$

where v_i is the average yield of the i^{th} variety relative to a base variety. This is likely to reduce the gaps in the data, since most varieties of any significance in a region are likely to have been included in trials in that region at some time.

For this approach, a form of analysis of relative yields from trials where there is incomplete variety-year data is required. Modified joint regression analysis (Digby 1979) is well suited, and can give superior results to simple means of trial relativities.

4.3 Relative Merits of the Index of Varietal Improvement

There are a number of limitations to using a varietal improvement index to measure the contribution of new wheat varieties to farm yields. First, as with O'Brien's approach, this measure implies that relative experimental yields represent the relativities that would occur on farms. Davidson and Martin (1965) found that the percentage advantage in yields that a new variety shows in trials is likely to be lower on farms. Thus the index itself cannot be taken as a measure of yield improvement on farms, but only as a measure of yield potential, and when used in a production function the coefficient is expected to be less than one.

Second, the use of relative average yields (v_i) as in equation (4.3) rather than the relative yield of each year (v_{it}) as in equation (4.2) means that the analysis implies a fixed (long-term) relativity of yields. Finlay and Wilkinson (1963) showed that varieties respond differently to changed environments, so that relative yields can be expected to be different for each season. Consequently, this approach will indicate long-term trends but will not be reliable in indicating year-to-year movements in yields. However, the high level of inherent year-to-year instability makes it unrealistic to expect any technique to give more than long term trends. Also, this approach assumes that the relativities do not change with time, and it is arguable that differential response to changing disease patterns, for instance, can change the relativities of varieties over time. It may be possible to overcome this change in relativity over time by using only results from, say, the last five years of trials in assessing relative yields. This possibility has not been explored in this paper.

Third, the index of varietal improvement is specific to a particular area. Because relative yields vary with environmental factors in different locations, the index cannot be constructed meaningfully for Australia as a whole, for a whole State or even for a large part of a State.

Fourth, the adjustment for the varieties excluded assumes that these varieties have the same average yields as those varieties included in the index. Data on varieties may not be available because a variety which was grown in the region had not been included in trials in that region, or because the varieties were not specified in the statistical collection process. To the extent that the varieties omitted are lesser-known or less well adapted, it is likely that their yields will be lower than the existing popular varieties (unless they are new varieties which have just been released). For example, detailed variety statistics show that in some years some farmers grow varieties that are clearly inferior-yielding varieties in trials. However, to the extent that the varieties omitted are not available because they were unspecified on the Agricultural Census form, it would seem reasonable that such varieties have the same average yields as those included in the index. Nevertheless, some overstatement of varietal contribution to yields can occur as a result of this adjustment. This could be overcome by assuming that these unspecified varieties have the same average yield as all varieties in some previous period. However, where the coverage of the varieties was high (say $\sum_i p_{it} > 0.9$), the assumption about non-specified varieties is likely to be sufficiently unimportant to make such refinements unwarranted.

Nevertheless, despite these limitations and qualifications, the index of varietal improvement appears to offer the only means of measuring the contribution of varietal improvement to production. Provided adequate data are available, and provided the study is sufficiently disaggregated to enable relative yields to be assumed to be reasonably constant over the region, the index of varietal improvement offers a useful means of incorporating a varietal effect into a production function. In that sense, it is simple to interpret, since a change in the level of the index represents a change in the level of yields. Thus although these limitations are real enough, they are not sufficient to prevent its use; rather, the limitations need to be borne in mind to ensure that the use of the index is restricted to studies in which it is appropriate, and that it is not used in the wrong context.

While there may be merit in attempting to include annual fluctuations in the index, such an approach would be subject to high statistical error. Thus the gains from using relative annual yields rather than relative average yields in the index may not be sufficient to outweigh the losses from reduced coverage. Therefore, the most practical form of the index is likely to be that based on relative average yields (that is 4.3), since it uses all available information to give a long-term measure. Only in specific cases where short-term fluctations were being examined in detail would the index based on relative annual yields (4.2) be preferred.

5. Empirical Analysis

5.1 Data

To examine those indexes empirically, data on wheat varieties from the Mitchell Shire in southern N.S.W. were used. Yields for the period 1950 to 1981 were taken from trials at the Agricultural Research Institute, Wagga Wagga, which is within the Shire boundary.

Data on the proportion of the total area sown to each variety for the period 1962 to 1979 were obtained from R. Fitzsimmons, Assistant Principal Agronomist (Cereals), N.S.W. Department of Agriculture (personal communication).

The 25 most popular wheat varieties in the Shire over that period were included in the analysis. The coverage of the total area sown to wheat ranged from 79 per cent to 99 per cent. The main reason for the lower coverage in the early 1960s was that the proportion of "unspecified" ranged up to 18.9 per cent.

5.2 Index of Varietal Improvement

The form of the index used for the initial analysis is that shown in equation (4.3), where the average relative yields are used rather than the relative yields from each year's trials. Yields from trials were analysed by unweighted modified joint regression (Digby 1979). The relative average yields are summarized in Table 1, where the yields of all varieties are expressed as a percentage of the yield of the variety Olympic, the only variety grown in the Shire throughout the period of the index.

Table 1: Estimates of Relative Yields of Varieties [a]
A.R.I., Wagga, 1950 to 1981

Variety	Year of Release	Yield as % of Olympic
Ford	1916	92.4
Bencubbin	1922	93.8
Bordan	1924	91.3
Koala	1936	97.5
Javelin	1942	82.0
Celebration	1944	78.6
Gabo	1945	100.4
Insignia	1946	102.4
Kendee	1946	88.4
Pinnacle	1946	96.8
Glenwari	1948	94.1
Sherpa	1953	99.8
Olympic	1956	100.0
Heron	1958	89.1
Falcon	1960	93.5
Gamenya	1960	91.8
Summit	1965	80.0
Robin	1966	85.5
Eagle	1969	99.4
Halberd	1969	93.3
Teal	1972	133.0
Condor	1973	124.6
Egret	1973	136.6
Kite	1973	103.5
Oxley	1974	137.8

[a] Based on analysis of wheat variety trial results from 1950 to 1981 using unweighted modified joint regression (Digby 1979).

Table 2: Calculation of Index of Varietal Improvement
Mitchell Shire, 1976 Season

Variety	Proportion of Total Area p_{it}	Relative Yield [a] v_i	Product $p_{it}\ v_i$
Condor	0.377	124.6	46.97
Eagle	0.076	99.4	7.55
Egret	0.075	136.6	10.25
Falcon	0.053	93.5	4.96
Gamenya	0.005	91.8	0.46
Heron	0.007	89.1	0.62
Kite	0.006	103.5	0.62
Olympic	0.282	100.0	28.20
Robin	0.003	85.5	0.26
Teal	0.098	133.0	13.03
	$0.982 = \Sigma p_{it}$		$112.92 = \Sigma p_{it} v_i$

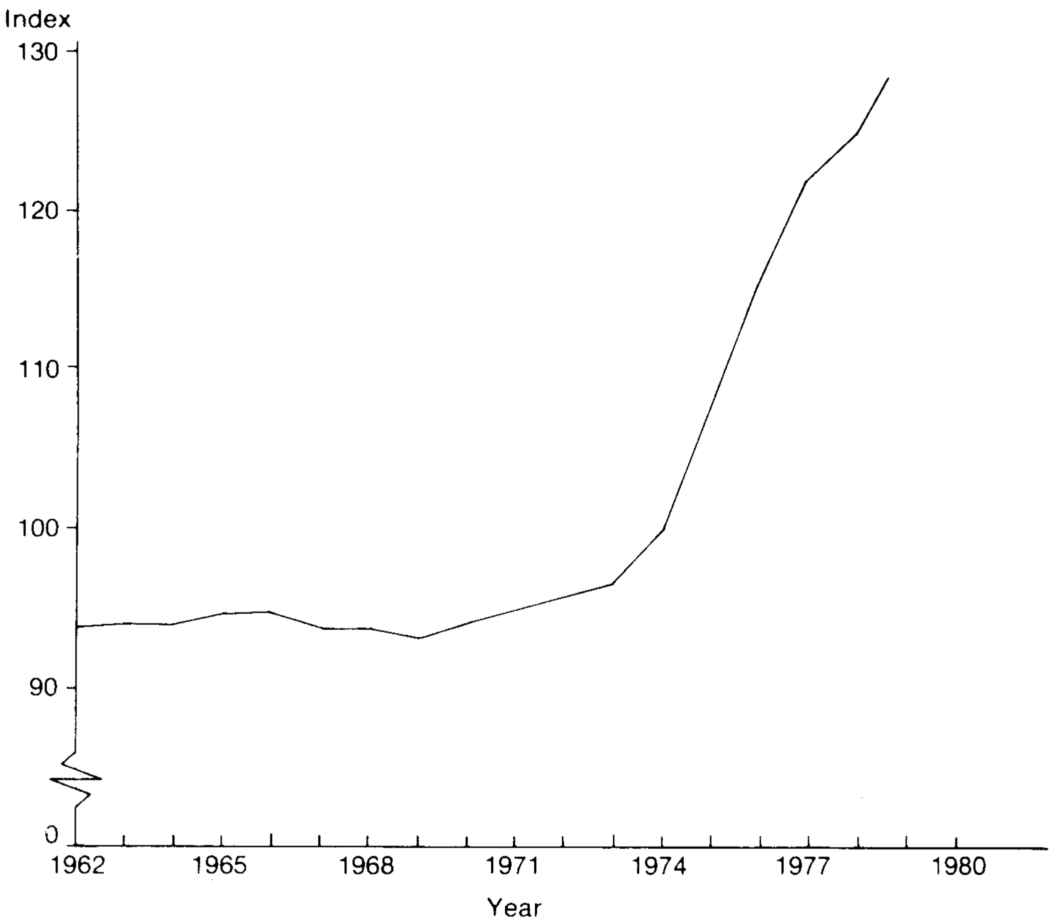
Index for 1976 $= (\Sigma p_{it}\ v_i)\ /\ \Sigma p_{it}$
$= 112.92\ /\ 0.982$
$= 115.0$

[a] Yield expressed as a percentage of the yield of the variety Olympic, from Table 1.

The calculation of the index for 1976 is illustrated in Table 2. The sum, over all varieties included, of the product of the proportion of the area sown and the relative yield was calculated. The resulting index figure of 115.0 provides a weighted measure of the relative yield of the varieties grown in 1976 as a percentage of the base variety Olympic.

The results of these index calculations using the 25 leading varieties are shown in the first column of Table 3. The index increased over the period by 37 per cent, with most of the increase occurring after 1973. The index is illustrated in Figure 2.

Figure 2: Index of Varietal Improvement[a]
Mitchell Shire[b]



a: Where $I_t = \left(\sum_i p_{it} v_i\right) / \sum_i p_{it}$.

b. Base Olympic = 100.0. Using 25 leading varieties.

Table 3: Index of Varietal Improvement[a]
Mitchell Shire, 1962 to 1979

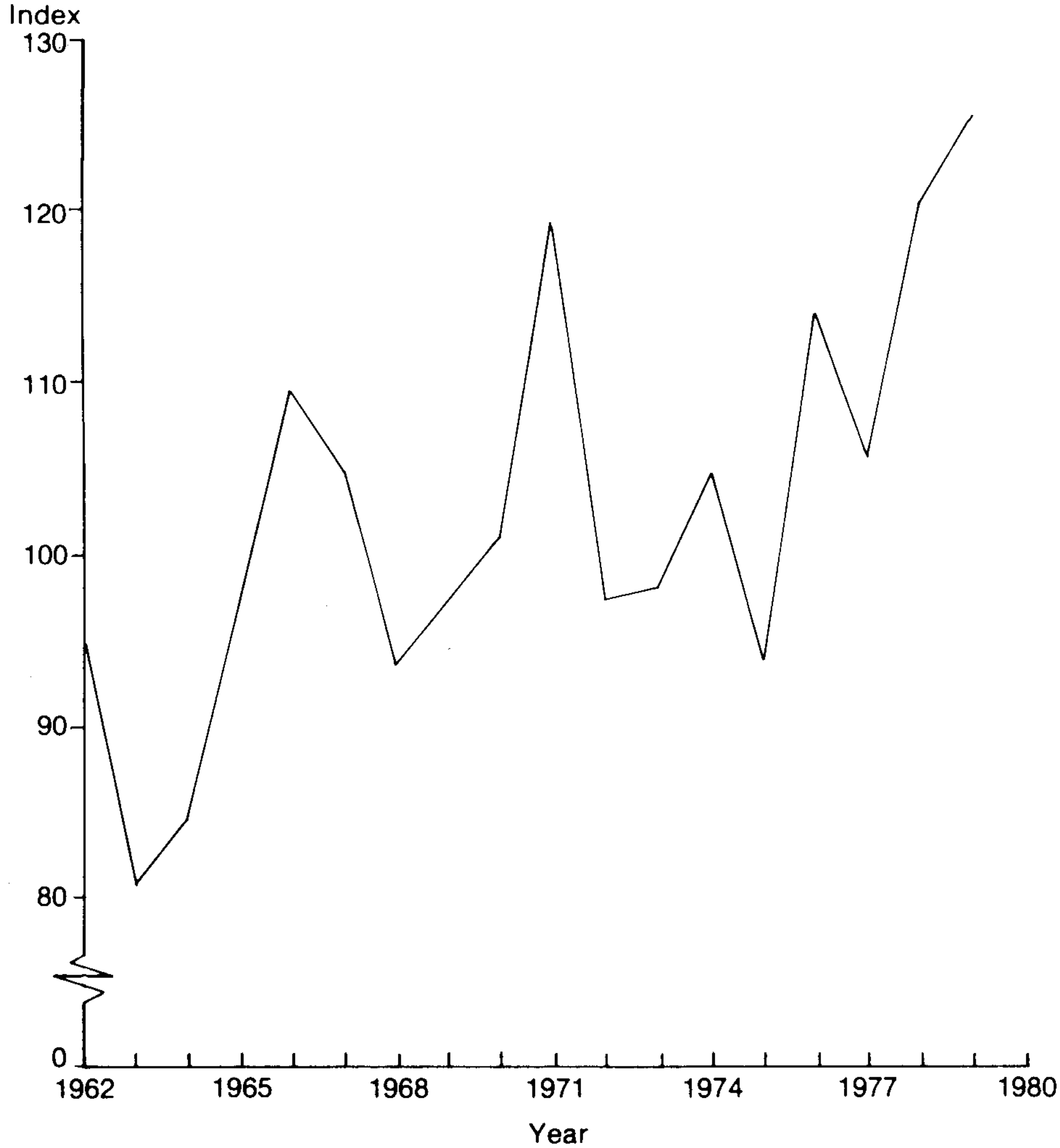
Year	Index (1)[b]	Index (2)[c]	Index (3)[d]
1962	93.6	94.2	96.0
1963	93.8	93.6	80.9
1964	93.6	93.5	84.6
1965	94.1	94.1	97.1
1966	94.3	94.3	109.5
1967	93.5	93.4	104.9
1968	93.3	93.3	93.3
1969	92.9	92.8	97.0
1970	93.8	93.9	100.9
1971	94.4	94.3	119.2
1972	95.4	95.5	97.2
1973	96.4	96.2	98.0
1974	99.7	100.9	104.6
1975	107.6	108.2	93.6
1976	115.0	115.5	114.0
1977	121.7	122.6	105.6
1978	124.6	125.1	120.4
1979	128.0	128.8	125.7

[a] Base Olympic = 100.0
[b] From equation (4.3), using 25 leading varieties.
[c] From equation (4.3), using only those varieties grown on five per cent or more of the area each year.
[d] From equation (4.2), using 25 leading varieties.

Two other forms of the index were also examined. The first involved restricting the coverage of varieties to those which were sown on more than five per cent of the total area. Thus in 1976, only six varieties rather than ten were used in the calculations (see Table 2). The results of restricting the analysis to major varieties each year are also shown as Index (2) in Table 3. The high correlation of the two forms of the index is apparent, even though the varieties included in Index (2) account for an average of 86 per cent of the total wheat area compared to an average of 93 per cent in the initial index series. The index in this form is higher in most cases than where minor specified varieties are also included. This upward "bias" in the index will occur wherever the importance of older varieties in this group is greater than new varieties. This is likely to be common, since many older varieties continue to be grown by some farmers for many years after they are outclassed, while new varieties which prove superior in yield are rapidly adopted by the majority of farmers. Therefore it appears likely that restricting the index to major varieties is likely to introduce a probably small upward bias in the index, although it may not have any effect on the change in the index over time.

The second alternative form of the index examined was that specified in equation (4.2), where the relative yields in trials each year (rather than the overall average, as used above) were weighted by the relative popularity of the varieties. The results are shown as Index (3) in Table 3. Because the varieties included in trials each year do not coincide precisely with those popular with farmers at that time, the coverage of total area was some 20 per cent lower than in the initial form of the index. Also, because the relative yields fluctuate with different seasonal conditions, the index fluctuates much more than when average relative yields are used. The movements of the

Figure 3: Index of Varietal Improvement[a]
Mitchell Shire[b]

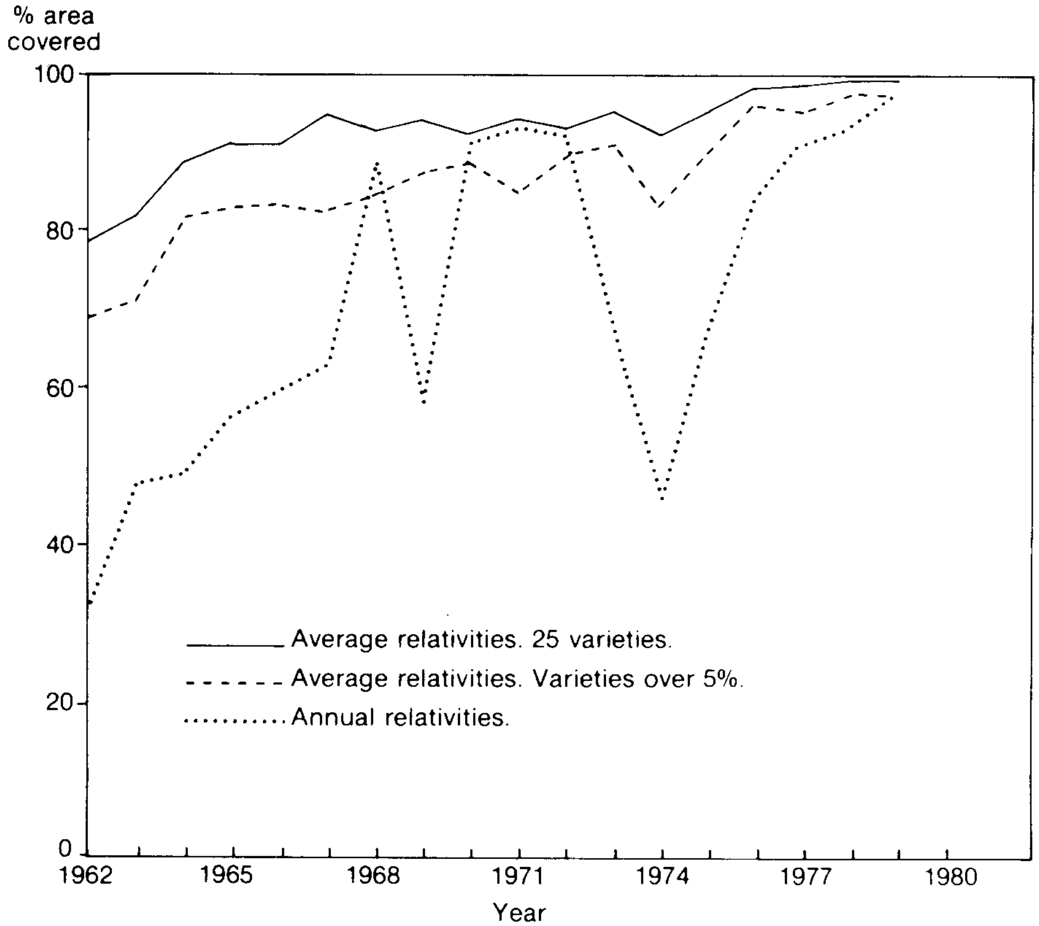


a: Where $I_t = \left(\sum_i p_{it} v_{it} \right) / \sum_i p_{it}$.

b: Base Olympic = 100.0.

indexes calculated in this way are illustrated in Figure 3. These movements are clearly different from those in Figure 2. While this method reflects more accurately the effects of seasonal conditions on relative yields, it places greater emphasis on the assumptions about the adjustment to account for incomplete coverage. Some of the annual movements in this form of the index

Figure 4: Proportion of Total Area of Wheat Covered by Different Indexes Mitchell Shire



may be due largely to the marked changes in coverage, making interpretation difficult. This is illustrated in Figure 4, where the proportion of the total area of wheat covered by the three different forms of the index is shown.

These examinations show that the form of the index of varietal improvement can have an important bearing on the results obtained. Once the most appropriate form of the index is chosen, the results are likely to be only marginally altered by restricting the coverage to major varieties each year, providing the coverage is at least, say, 80 per cent of the area. However, some bias could be introduced by restricting the coverage to major varieties.

5.3 Index of Varietal Newness

The generalized form of the index, as specified in equation (2.4), was used. The index was calculated for $n = 1$, $n = 2$ and $n = 5$ (equivalent to Johnson and Gustafson). The calculation of the index for 1976, $n = 5$, is illustrated in Table 4. In 1976, none of the varieties which made a

Table 4: Calculation of Index of Varietal Newness
Mitchell Shire, 1976 Season

Variety	Proportion of Wheat Area				z_{it}[a]	x_{it}[b]
	1976	1971	1966	1961		
Condor	0.377	0	0	0	0.377	0.377
Eagle	0.076	0.046	0	0	0.030	0.030
Egret	0.075	0	0	0	0.075	0.075
Falcon	0.053	0.313	0.250	na	<0	0
Gamenya	0.005	0.020	0.029	na	<0	0
Heron	0.007	0.105	0.260	na	<0	0
Kite	0.006	0	0	0	0.006	0.006
Olympic	0.282	0.316	0.270	na	<0	0
Robin	0.003	0.114	0	0	<0	0
Teal	0.098	0	0	0	0.098	0.098
Others	0.018	0.086	0.191	na	na	na
						$\Sigma x_{it} = 0.586$

[a] $z_{it} = p_{i,t} - p_{i,t-5} - 2p_{i,t-10} - 3p_{i,t-15} - \ldots$
[b] $x_{it} = z_{it}$ if $z_{it} \geq 0$,
$= 0$ if $z_{it} < 0$.
na Not available.

contribution to the index were available in 1961, so there were no difficulties in assuming that these varieties were not grown in 1961 or earlier. The only varieties available before that time were grown in sufficient quantities in 1966 and 1971 to ensure they did not contribute to the index in 1976. However, for the period 1962 to 1968 and for some years after that, the lack of data from earlier years made it impossible to calculate the index. The values of the index for the years in which the data allowed calculation are shown in Table 5, and

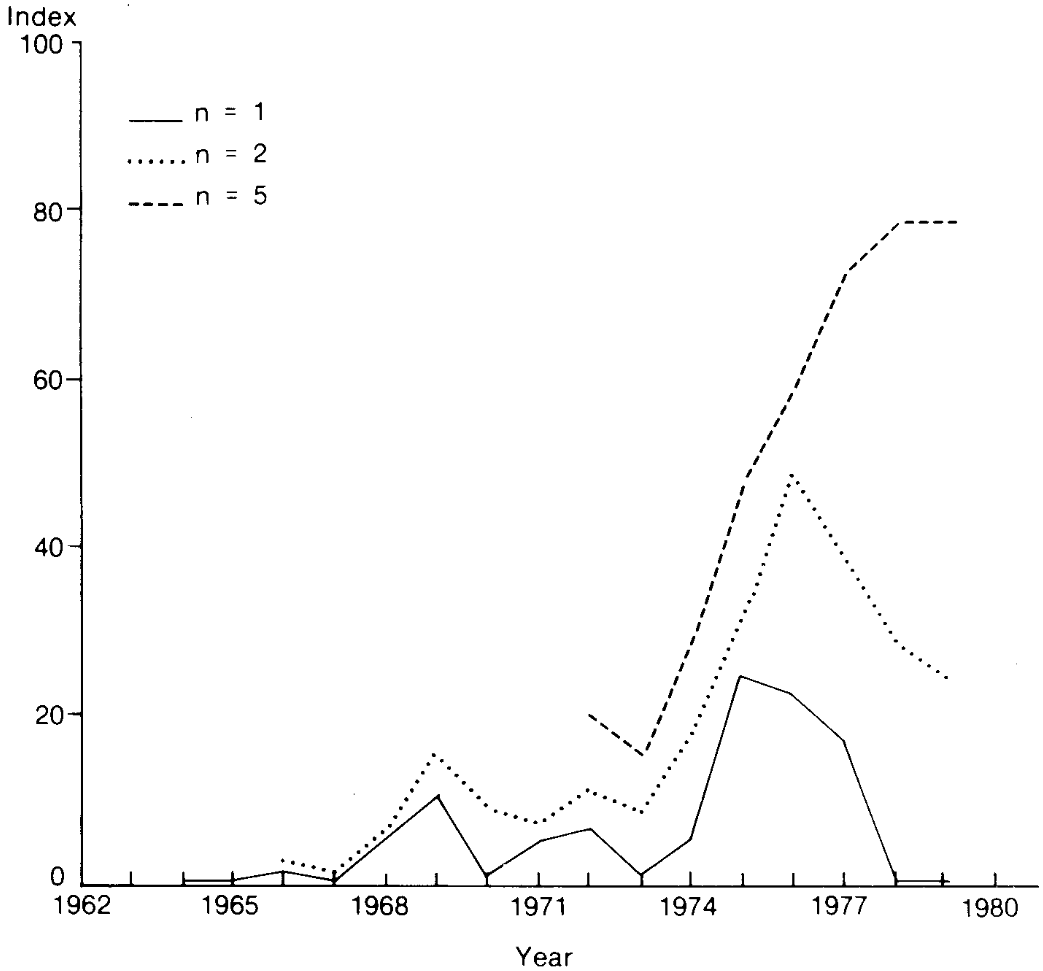
Table 5: Index of Varietal Newness[a]
Mitchell Shire, 1962 to 1979

Year	Index of Varietal Newness		
	n = 1	n = 2	n = 5
1962	na	na	na
1963	na	na	na
1964	0.1	na	na
1965	0.2	na	na
1966	1.6	2.5	na
1967	0.1	1.2	na
1968	5.5	5.8	na
1969	10.2	15.8	na
1970	1.3	9.4	na
1971	5.5	6.9	na
1972	6.3	11.1	20.0
1973	1.0	8.4	15.5
1974	5.8	18.0	29.0
1975	24.6	32.0	47.8
1976	22.5	48.9	58.6
1977	16.8	38.8	73.1
1978	0.0	29.5	78.5
1979	0.1	25.3	78.9

[a] As specified in equation (2.4).
na Not available.

Figure 5: Index of Varietal Newness

Mitchell Shire[α]



α: As specified in equation (2.4).

are illustrated in Figure 5. It is evident that the index of varietal newness varies markedly for different values of *n*. Thus the choice of *n* becomes critical to the results obtained. It follows from the use of lagged values that the smaller is *n* the longer that period the index can be calculated for with a given amount of data.

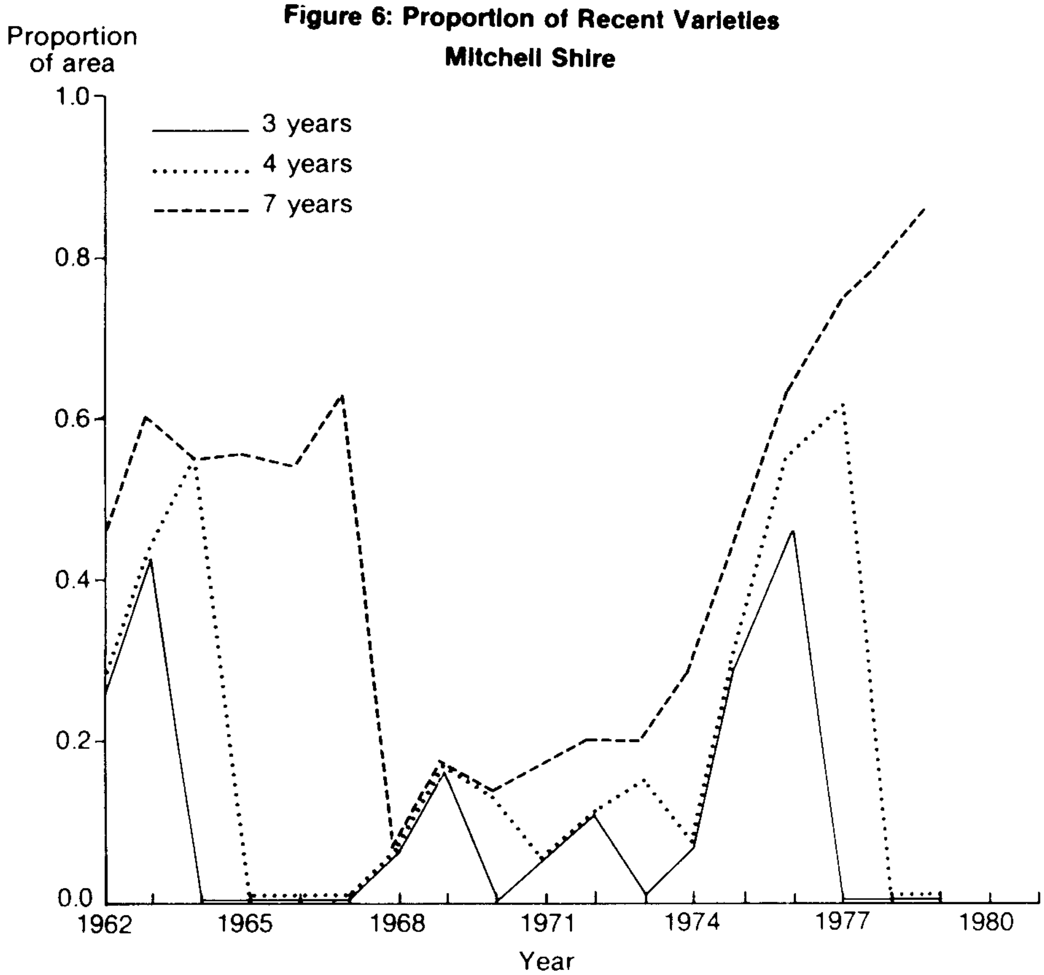
5.4 Proportion of Recent Varieties

This measure was calculated for three different definitions of "recent", namely three, four and seven years. This was seen as equivalent to the values of *n* used in the index of varietal newness, given the two years' delay before seed is widely available. The results are shown in Table 6, and illustrated in Figure 6. Once again, it is evident that different definitions of "recent" can lead to very different results, so that the choice of length of period is critical to the results obtained.

Table 6: Proportion of Recent Varieties Mitchell Shire, 1962 to 1979

Year	Proportion of Recent Varieties		
	3 years	4 years	7 years
1962	0.242	0.242	0.425
1963	0.431	0.431	0.613
1964	0.0	0.547	0.547
1965	0.0	0.0	0.559
1966	0.0	0.0	0.539
1967	0.0	0.0	0.628
1968	0.056	0.056	0.056
1969	0.156	0.156	0.156
1970	0.0	0.131	0.135
1971	0.046	0.046	0.168
1972	0.106	0.106	0.196
1973	0.010	0.139	0.200
1974	0.067	0.067	0.285
1975	0.322	0.322	0.470
1976	0.458	0.556	0.632
1977	0.0	0.621	0.726
1978	0.0	0.0	0.793
1979	0.0	0.0	0.855

Figure 6: Proportion of Recent Varieties Mitchell Shire



5.5 Correlation Between the Measures

The correlation coefficients between the different measures that have been discussed are shown in Table 7. Since the index of varietal newness could not be calculated for the full period of the data, the correlation coefficients for the shorter periods are shown. These correlations are likely to be different than if the full period could have been used.

Table 7: Correlation between Different Measures of Varietal Improvement Mitchell Shire, 1962 to 1979

	IVI (1)	IVI (2)	IVI (3)	IVN (n=1)	IVN (n=2)	IVN (n=5)	Prop (m=3)	Prop (m=4)	Prop (n=7)
IVI(1)	1.000								
IVI(2)	1.000*	1.000							
IVI(3)	0.639*	0.638*	1.000						
IVN(n=1)	0.295[a]	0.301[a]	-0.075[a]	1.000					
IVN(n=2)	0.794[b]*	0.798[b]*	0.277[b]	0.717[b]*	1.000				
IVN(n=5)	0.991[c]*	0.993[c]*	0.769[c]*	0.092[c]	0.705[c]	1.000			
Prop (m=3)	0.003	0.006	-0.296	0.844[a]*	0.610[b]*	-0.059[c]	1.000		
Prop (m=4)	0.032	0.034	-0.566*	0.379[a]	0.445[b]	0.116[c]	0.222	1.000	
Prop (m=7)	0.685*	0.682*	0.332	0.036[a]	0.565[b]*	0.994*	0.069	0.157	1.000

[a] 1964 to 1979 only.
[b] 1966 to 1979 only.
[c] 1972 to 1979 only.
* Significant at 5% level.

The three different measures are generally not highly correlated, although there is high correlation in isolated cases. The extremely high correlation between IVI(1) and IVI(2) has been discussed above. Overall, only eight of 36 coefficients are greater than 0.8. The lack of correlation reflects the different results with different definitions of "newness" and "recent", as well as the already stated difference that the index of varietal improvement measures changes in yield while the index of varietal newness and proportion of recent varieties measure the rate of change of varieties. Thus different results can be obtained, depending on which measure is used.

6. Summary and Conclusions

The effect of varietal change on farmers' production can be represented in a production function in a number of ways:

(a) by an index of varietal newness (a weighted indicator of the proportion of the area sown to varieties not sown in earlier periods);

(b) by the proportion of the area sown to recently released varieties; or

(c) by an index of varietal improvement (where the relative yield of each variety is weighted by the proportion of the area sown to that variety).

The choice between them will be determined by the degree of aggregation required, the availability of data and the aims of the researcher. The index of varietal improvement is only suited to disaggregated studies of regions where relative yields would be reasonably constant, while the index of varietal newness and the proportion of recent varieties may be better suited to general aggregated studies (perhaps at State or national level). The index of varietal improvement requires data on relative yields, either relative annual or relative average yields over a number of years, as well as data on the relative popularity of varieties with farmers. The other measures only require data on the relative popularity of varieties. However, where these data are not available over a long period, the index of varietal newness can only be calculated over part of the period. In view of this, the index of varietal newness appears to have little advantage over the simpler proportion sown to recent varieties. However, neither of these measures gives any indication of the yield or production effects, so in detailed production studies the index of varietal improvement is likely to give more information and provide more meaningful interpretation. Therefore the index of varietal improvement is the preferred measure to use in a detailed production function, provided adequate data are available.

Measures of the contribution of varietal change to increasing wheat yields in the Mitchell Shire are not clear for the 1960s, although all measures show a major contribution in the mid to late 1970s from the introduction of semi-dwarf varieties. For example, the index of varietal improvement (the preferred measure) increased from 93.6 to 96.4 between 1962 and 1973, then increased to 128.0 by 1979. The extent to which these increases determined from variety trials were translated to increases in wheat yields on farms can only be determined when the variables are incorporated in a production function with measures of other inputs including weather, rotations and fertiliser variables. The index of varietal improvement is the only one of the three measures examined which would enable ready interpretation in a production function and which could be used to examine interactions between varieties and other inputs.

References

AUER, L. (1963). "Impact of crop-yield technology on U.S. crop production." Unpublished Ph.D. thesis, Iowa State University of Science and Technology, Ames, Iowa.

AUSTIN, R. B., BINGHAM, J., BLACKWELL, R. D., EVANS, L. T., FORD, M. A., MORGAN, C. L. and TAYLOR, M. (1980). "Genetic improvements in winter wheat yields since 1900 and associated physiological changes". *Journal of Agricultural Science, Cambridge* 94, 675-89.

BRENNAN, J. P. (1983). "A comment on Victorian wheat yield trends". *The Journal of the Australian Institute of Agricultural Science* 49, 212.

BYERLEE, D. and HARRINGTON, L. (1982). "New wheat varieties and the small farmer". Paper presented to the Conference of the International Association of Agricultural Economists, Djakarta, Indonesia, August.

CAMPBELL, K. (1977). "Plant breeding to what purpose?". *The Journal of the Australian Institute of Agricultural Science* 43, 48-52.

DAVIDSON, B. R. and MARTIN, B. R. (1965). "The relationship between yields on farms and in experiments". *Australian Journal of Agricultural Economics* 9, 129-40.

DAVIDSON, J. L. and BIRCH, J. W. (1980). "Yield trends from Australian wheats". *Proceedings of the Australian Agronomy Conference*, Queensland Agricultural College, Lawes, 231.

DIGBY, P. G. N. (1979). "Modified joint regression analysis for incomplete variety x environment data". *Journal of Agricultural Science, Cambridge* 93, 81-6.

EVANS, L. T. (1980). "Response to challenge: William Farrer and the making of wheat — Farrer Memorial Oration 1979". *The Journal of the Australian Institute of Agricultural Science* 46, 3-13.

FINLAY, K. W. and WILKINSON, G. N. (1963). "The analysis of adaptation in a plant-breeding programme". *Australian Journal of Agricultural Research* 14, 742-54.

GODDEN, D. and POWELL, R. (1981). "Economic aspects of Plant Variety Rights, models for examining their effects". Paper presented to the 51st ANZAAS Congress, Brisbane.

HEADY, E. O. and AUER, L. (1966). "Imputation of production to technologies". *Journal of Farm Economics* 48, 309-22.

JOHNSON, D. G. and GUSTAFSON, R. L. (1963). *Grain Yields and the American Food Supply: An Analysis of Yield Changes and Possibilities*, Second Impression. University of Chicago Press, Chicago.

MACINDOE, S. L. and WALKDEN BROWN, C. (1968). *Wheat Breeding and Varieties in Australia*, N.S.W. Department of Agriculture, Science Bulletin No. 76.

O'BRIEN, L. (1982). "Victorian wheat yield trends, 1898-1977". *The Journal of the Australian Institute of Agricultural Science* 48, 163-8.

RUSSELL, J. S. (1973). "Yield trends of different crops in different areas and reflections on the sources of crop yield improvement in the Australian environment". *The Journal of the Australian Institute of Agricultural Science* 39, 156-66.

SILVEY, V. (1978). "The contributions of new varieties to increasing cereal yield in England and Wales". *Journal of the National Institute of Agricultural Botany* 14, 367-84.

SILVEY, V. (1981). "The contribution of new wheat, barley and oat varieties to increasing yield in England and Wales 1947-78". *Journal of the National Institute of Agricultural Botany* 15, 399-412.

WARREN, J. F. (1969). "Australian wheat yield trends". *The Journal of the Australian Institute of Agricultural Science* 37, 303-13.